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Utilising the Internet of Things for the Management of Through-life Engineering Services on Marine Auxiliaries

Moritz von Stietencron[a,*], Carl Christian Røstad[b], Bjørnar Henriksen[b], Klaus-Dieter Thoben[a,c]

[a]*BIBA - Bremer Institut für Produktion und Logistik GmbH at the University of Bremen, Hochschulring 20, 28359 Bremen, Germany*
[b] *SINTEF Technology and Society, S.P. Andersens vei 5, N-7465 Trondheim, Norway*
[c]*Faculty of Production Engineering, University of Bremen, Badgasteiner Straße 1, 28359 Bremen, Germany*

* Corresponding author. Tel.: +49-421-21850117; fax: +49-421-2189850117. *E-mail address:* sti@biba.uni-bremen.de

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Abstract

The producers of marine auxiliaries face the challenge, that they need to adapt their schedule for maintenance, repair and overhaul (MRO) operations and other Through-life Engineering Services (TES) to the otherwise defined and often not well communicated schedules of the ships, which are carrying their products. The management of the MRO operations is currently a manual and time-consuming effort and makes the creation of Product Service Systems (PSS) a tedious effort. To help overcome this – unnecessary – hurdle, this paper presents a solution approach and its prototypical implementation utilising the Internet of Things (IoT) to aid the marine auxiliaries' producers in the process of managing the product usage phase and its services. As data basis for the decision support, the constantly produced information of the Automatic Identification System (AIS) is used, and combined with Product Usage Information and enterprise data.

Keywords: Internet of Things; MRO; Through-life Engineering; Product Service Systems; Marine Industry, Product Usage Information

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1. Introduction

Through-life Engineering Services (TES) have become increasingly important for many producers of knowledge-intensive products over the last decade. Both with regards to the optimization of their products conventional usability as well as for unlocking new and complementary business models. [1] For the producers of marine auxiliaries, alone the scheduling of maintenance, repair and overhaul (MRO) operations is a task which is consuming substantial resources. With the more and more readily available Internet of Things (IoT) technologies, new approaches for decision support in the management of TES is becoming available.

This paper presents an approach based on two different IoT systems, the Automatic Identification System (AIS) and Product Embedded Information Devices (PEIDs) to foster intelligent management of MRO operations for marine auxiliaries and their producers. Based on the general motivation, related work and presentation of the methodology, a practical specification and implementation of a decision support system along two development tracks are presented. The paper concludes with a summary of the findings and an outlook to future work.

2. Background and Motivation

The procurement of MRO - and also other TES related - operations is regularly a process which requires physical access to the core product. For stationary deployed products this is already in many cases an issue because the product context needs to be altered, e.g. the production stopped. For mobile products, however, another dimension of complexity is introduced with regards to the management of TES operations like MRO scheduling: the product's changing location.

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For the producers of marine auxiliary components, the latter problem is even increased by the fact, that while their products may be important to the operation of the ship, they regularly do not have a high enough significance to influence possible schedules and locations. They are thus highly dependent on the defined schedules of the ship owning companies and subsequently need to adapt their operations planning to the ships' schedules.

Currently, the management effort used to overcome this dilemma is a time consuming and manual one. Ships which carry products requiring service are identified and the respective ship owning companies are contacted to ask for possible timeslots while in the roadstead. Coordination of MRO efforts over multiple ship owning companies and harbours is virtually impossible as the information are very short lived, which results in a plethora of redundant and unnecessary travels.

Some companies have already begun to utilize the information provided by websites like MarineTraffic [2] which present both historical and forecast data from the AIS system. However, this practice either binds the users to the consumer-oriented user interface offered for free or at little costs by the service providers or invokes high costs for data acquisition and integration into the enterprise systems.

The approach presented in this paper shows ways to combine data from various data sources like AIS and enterprise systems in a cost effective and efficient way to enable marine auxiliaries producers to intelligently manage TES on their products. Additionally, to the location based decision support, possibilities for the integration of product usage information are being investigated, leading to an approach with two development tracks, one for the acquisition of product location data and one for the acquisition of product usage information.

3. Related Work

The following gives an overview of the relevant state of the art regarding the main technologies of the topics Through-life Engineering Services and Internet of Things which are the foundation relevant to the methodology and solution approach described in the succeeding chapter.

3.1. Through-life Engineering Services

Through-life Engineering Services (TES) are a type of product extension services. They help guarantee the required and predictable performance of an engineering system throughout its expected operational life with optimum whole life cost. [1] In order to mitigate degradation, restore lost functionality and maximize product availability, they apply service knowledge from product usage, maintenance, repair and overhaul [3]. With this knowledge processes, such as future product design, product improvements, usage support, additional service offers or end-of-life decisions can be subsequently improved.

Many different concepts support the development and procurement of TES. For the development presented in this paper, the technical approach to Product Lifecycle Management, the paradigm of digitized products and the concept of servitization are key enablers for TES. They are introduced in the following subsections.

3.1.1. PLM – Product Lifecycle Management

Product Lifecycle Management (PLM) can be interpreted from the marketing as well as from the production engineering perspective. [4] The production engineering perspective often divides the product's lifecycle into three main phases: beginning-of-life (BOL), middle-of-life (MOL) and end-of-life (EOL). [5] The BOL comprises steps such as product development, production, and distribution while the MOL represents the use phase and the EOL the reverse logistics. BOL and EOL are regularly of little interest to the customer or end user, while the MOL is in direct interaction with the user. [6]

Frequent interaction between product and producer in the MOL phase is thus hindered by the customers. This is even increased in control and security sensitive industries like the maritime sector.

However, for closed-loop PLM it is crucial to combine information flows of as many product phases as possible. [7] For the integration of the MOL phase as the regularly longest phase technologies that enable product – producer interaction without customer involvement, technologies like the Internet of Things (IoT) need to be employed.

3.1.2. Digitized Products

Informatization is referring to the process of collecting, storing and analysing data from customers and end-users of products and services and often serves the goal to discover new needs or identify changes in usage patterns enhancing existing offers or the related service-level agreements (SLAs) back to the customer. [8] It is systematised as an information feedback loop beginning with collecting and storing data from customers, analysing it to create data about them, and providing information about new service offerings back to the customer, after which the loop is repeated. [8] In Product Service Systems (PSS) multiple of such information feedback loops are regularly opened amongst the stakeholders in a whole PSS network, as the PSS are seldom provided by an individual company.

The rise of PSS themselves can be seen as one of the main sources of information for these feedback loops. Digitalized products are those, which have seven material properties: programmability, addressability, sensibility, memorability, communicability, traceability, and associability [9]. This enables loosely coupling devices, networks, services, and contents – the four layers of a digital service architecture. Concepts for "digitalized" products are often referred to as smart or intelligent products. These are physical products which are extended beyond their traditional use, by enabling them to act in an intelligent manner. McFarlane et al. define the Intelligent Product as "a physical and information-based representation of an item [...] which possesses a unique identification, is capable of communicating effectively with its environment, can retain or store data about itself, deploys a language to display its features, production requirements, etc., and is capable of participating in or making decisions relevant to its own destiny." [10] Intelligent product may have intelligence ranging from simple data processing to complex pro-active behaviour [11]. Digitized or intelligent products can thus comprise e.g. of RFID, sensors, and embedded computing to collect information about their usage, service, maintenance, upgrade, decommission and disposal throughout their lifecycles and feed it back to stakeholders responsible for the PSS offer.

3.1.3. Servitization

The term “servitization” characterizes the change of the producers business model from product sales towards the conversion of service offers along the entire product lifecycle and was established by Vandermerwe and Rada [12]. These service offerings can be both product extending as well as product maintaining (e.g. MRO). Reasons for servitization can be seen from economic, environmental or strategic perspectives. [13] For knowledge-intensive products servitization (by the producer) is traditionally a widespread approach to supplying the customer with the through-life services he and his product need. Marine auxiliaries can be included in this consideration as they regularly have to fulfill strict regulations both in production as well as during service.

3.2. IoT - Internet of Things

The product services of the 21st century are broadly supported by and reliant on the internet [14]. This trend is dramatically increased by the possibilities of the Internet of Things (IoT).

The Internet of Things can be seen as an evolution of the “old” human driven internet towards an internet which is driven by inanimate objects – things [15]. Originating in the wake of radio frequency identification (RFID) technology the IoT encompasses every object that participates in data exchange with other systems. It does not make any difference whether this exchange is multilateral or not, neither what sort of system is observed. [16]

For the implementation of the IoT in the developments presented in this paper, two technologies have a central role. The approach of Product Embedded Information Devices and the Automatic Identification System for ships. Both will be introduced in the following subsections.

3.2.1. PEID - Product Embedded Information Devices

The PROMISE Consortium [17] describes a matrix of characteristics for the implementation of implementations of intelligent products, so-called Product Embedded Information Devices (PEIDs) as shown in Table 1

Table 1. Types of PEIDs according to [17].

Type	Identification	Data Storage	Sensors	Data Processing	Connectivity
0	✓				Passive
1	✓	✓			Passive
2	✓	✓	(✓)	+	Wireless
3	✓	✓	✓	++	Wireless
4	✓	✓	✓	+++	Always

PEIDs are categorized according to four types. Identification is the sole necessary characteristic for any type. The other characteristics (data storage, sensors, data processing and connectivity) are optional; the higher the type, the more optional characteristics the PEID has and consequently the more complex the device embedded into the product must be.

3.2.2. AIS - Automatic Identification System

The Automatic Identification System (AIS) for ships was developed as a system to make ship traffic safer by avoiding accidents due to human errors or technological insufficiencies like impaired radar sight. [18,19] The International Maritime Organisation issued a guideline for its use in 2002 [20] and thus forced the mass introduction of the system.

The AIS messages are sent automatically at a defined interval and can be received and read by anyone within the proximity of the sender as the VHF radio technology is used. Typically, a range of 10 to 20 nautical miles can be reached but this strongly depends on the hardware choice and geographical parameters. [21] The standardized AIS messages convey information about the ship, its position and also its current voyage [18].

Since its initial development one and a half decades ago both the capabilities and uses of the AIS have been constantly extended. For example, satellite-based AIS (S-AIS) can now also cover the oceans beyond the reach of shore-based receivers [22]. The data which is being generated by hundreds of thousands of ships every minute is also put to use in increasingly various fashions. From collision avoidance systems [23] over marine traffic engineering and harbour traffic management [24] to homeland security applications [25], [26] the applications are still mostly confined to the original idea of AIS – increasing security, safety and efficiency of the vessel and the traffic system.

4. Approach

This section describes the approach used to address the problem stated in the second chapter by utilizing the technologies and concepts introduced in the preceding section with a special focus on the use case presented below.

4.1. Use Case

TeamTec AS is a Norwegian producer of marine auxiliaries. Its main products are incinerators for onboard waste treatment, stripping ejectors (fluid driven jet pumps) and ballast water treatment system. It has over 30 years of history and thousands of products installed on ships worldwide. The TeamTec incinerators are high knowledge products which are serviced only by TeamTec or affiliated service providers. During the business case evaluation phase of the on-going research project “Innovativ Kraft” which is funded by the Research Council of Norway, the TES shown in Table 2 have been identified as relevant for improvement.

Table 2. Through-life Engineering Services identified for improvement.

No.	Through-life Engineering Service
S1	Predictive Maintenance
S2	MRO planning
S3	New value adding product Services

Predictive maintenance and the planning of MRO operations refer to current everyday processes for which potential for improvement is seen while generating new value adding product services is an endeavor to explore possibilities to extend the business models. For this set of services, the following tasks have been identified as starting points:

1. (automated) acquisition of ship data
2. (automated) acquisition of product data

Furthermore, three general objectives have been identified which are listed in table 3 and have been assigned a perceived significance for the project. This table is extended, for the two development tasks introduced above, in the tables 3 & 4. Both the decision to split the development into two tracks as well as the definition of the objectives have been achieved in meetings with the project development team and the process stakeholders.

Table 3. Summary of general objectives identified.

No.	Objective Content	Significance
O1	Flexible Data Mapping with Enterprise Data	High
O2	Low Total Cost of Ownership	Low
O3	Data Ownership	Medium

The following sections will briefly introduce the status quo of the identified potentials and present the approach chosen to address them.

4.2. Ship Data Acquisition

4.2.1. Status Quo

With a very high number of concerned ship owning companies, the administrative effort to coordinate a resource effective schedule for MRO operations on their products is immense. The updating of information regarding the ships carrying the products is completely manual up to now, using different AIS based internet services and compiling the data in spreadsheets.

4.2.2. Solution Approach

During meetings with the process owners and experts for information technology and industrial process design the requirements were identified. The following table presents them together with their significance. They can be read as a development track specific extension of Table 3.

Table 4. Summary of specific objectives identified for ship data acquisition.

No.	Objective Content	Significance
O4	Information about next Port of Call	High
O5	Information about Estimated Time of Arrival	High
O6	Search / Order by IMO Number	Medium

In a feasibility study, it was found that the three objectives with regards to the data content (O4-O6) can be achieved by the use of AIS data. This development track therefore mainly utilizes the IoT technology of the AIS to enable TES through Servitization and better PLM.

4.2.3. Prototypical Implementation

For the implementation, a six-step approach was chosen as shown in Fig. 1, below. The implementation of this development track is also covered in more detail in [27].

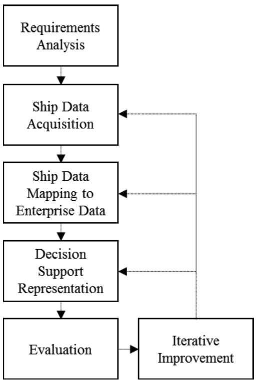


Fig. 1. Block diagram of chosen methodology

4.2.3.1. Ship Data Acquisition

Regularly, the information selected from the AIS system (see table 3, O4 & O5) remain static during a single voyage, thus uniform AIS coverage over the whole sea surface is not required in the current phase of this use case. Therefore satellite-based AIS service is not needed directly but should be considered as an option for later implementation. After a market analysis, it was decided to join the AISHub Data Sharing Network [28]. The AISHub provides access to AIS data concerning over 23500 vessels, which is filtered for the relevant ships in the system and is stored in a database.

4.2.3.2. Ship Data Mapping to Enterprise Information

Information about the relevant ships comes from the ERP system and is uniquely identified by the IMO number as means of identification of the product containing ship. Against this data table, the incoming AIS stream is compared and only the messages concerning the relevant ships are further processed.

The stored information from the ERP system and the AIS system are linked via the project reference. On the ERP system, it links to all information regarding the product, while the AIS system links to the installation and subsequently to the ship.

4.2.3.3. Decision Support Representation

From the information of the different systems, various views can be generated. Currently, three views have been implemented:

The vessel list view shows the vessels registered in the system with some details for vessel identification and the project reference. The vessel information view shows the current AIS data sets for the vessels and gives information about the current location, next port of call and estimated time of arrival of the vessel.

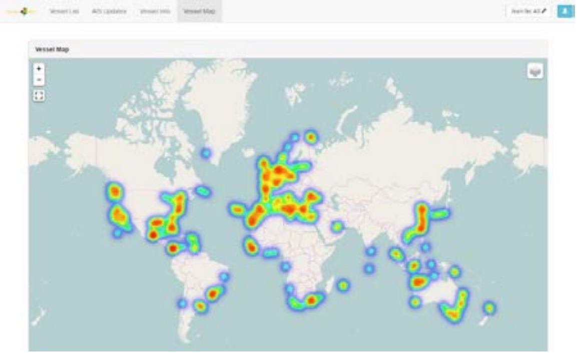


Fig. 2. Screenshot of the current positions of approximately 6000 selected vessels displayed as heat map

Finally, the vessel map gives an overview of the positions of all selected ships on a world map. This map can also be adjusted to show the next destinations of the ships. Additional features like a heat map layer can be activated on the map, to allow for easy analysis of the main areas of travel of the company's products. Figure 2 gives an example of the heat map view. Filters can be applied to all views to allow for quick navigation even in large amounts of data.

4.2.3.4. Evaluation and Iterative Improvement

For the evaluation of the system the progress of the development has been presented during multiple meetings. The feedback was collected and included in the ongoing development process.

4.3. Operating Data Acquisition

4.3.1. Status Quo

TeamTec incinerators have data processing capabilities in their control devices which manage data from the system and its sensors. However, these data are currently only retrieved manually during inspections and also not on every occasion, but only on separate trigger.

4.3.2. Solution Approach

This development track will extend the products existing computational capabilities towards data pre-processing as well as introducing internet connectivity are two key steps in tapping the data wealth that these products can provide.

The goal is to embed a continuous data assessment and alert system into the product which will assess the current operation data and both create a rolling condition schema which can be used for product optimization and long-term control as well as emit instant alerts if there is a threat to the proper execution of the TES or the product itself. These objectives have been summarized in the table below and can be read as a development track specific extension of Table 3. In contrast to the first development track here the IoT approach of the PEIDs is utilized to create a digitized product.

Table 5. Summary of specific objectives identified for product data acquisition.

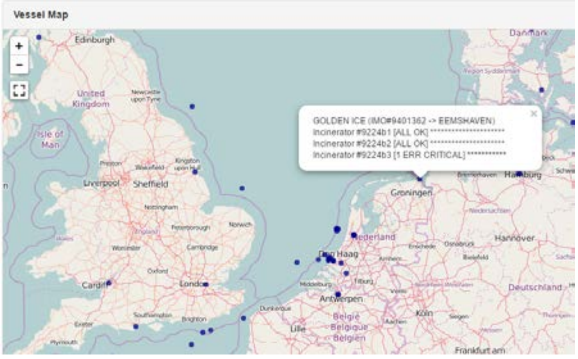
No.	Objective Content	Significance
O7	Automated, Rolling System Status Updates	High
O8	Instant System Error Alarms	Medium

TES complementary to the regular operation of the system, like the identified MRO operations and predictive maintenance, can be either instantly triggered from alarms as well as planned in advance based on the synthesized status reports which are continuously being created and sent at intervals. As most of the sensor values used for the control of the incinerators are already available as manual log output the low-level acquisition of data is not a concern of this use case.

4.3.3. Prototypical Implementation

Raw data transmission is not the preferred goal of the project, as this would incur large volumes of data usage which can be avoided by on-board data pre-processing. For the immediate dispatch of alarms, continuous connectivity is, of course, necessary. As this is an issue especially for vessels travelling out of cellular network reach, alternative transmission modes like satellite connection can be considered, however, the respective connection costs always need to be taken into account. Thus for most applications, instead enabling of message buffering until cellular networks are available is an acceptable compromise.

For the pre-processing and integration of the data which is being gathered by the incinerators control computer the experiences from the EC-funded research projects "BOMA – Boat Management" (EU FP7, 12/2011-11/2013), "ThroughLife" (EU FP7, 04/2011-03/2014) and "Fortissimo – HighSea Experiment" (EU FP7, 10/2014-12/2016) which all are concerned with usage data acquisition in the maritime industry will be employed. The "Universal Marine Gateway" which has been developed over these projects can collect data from heterogeneous data sources as well as pre-process and transmit it to downstream systems in the enterprise cloud. In this application, it will be extended to accept preformatted data from the control computer instead of directly reading sensor data.



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GOLDEN ICE (IMO#9401362 -> EEMSHAVEN)
Incinerator #9224b1 [ALL OK] **********************
Incinerator #9224b2 [ALL OK] **********************
Incinerator #9224b3 [1 ERR CRITICAL] ***********
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Fig. 3. Screenshot of product data representation associated with a product.

Similar to the decision support visualization of the ship data also the product data can be explored manually. Figure 3, below, gives an example of data associated with a product and subsequently the carrying ship. The representation of both ship, as well as product data, can, of course, be combined both in visualization as in use with analytics solutions.

4.4. Data Mapping with Enterprise Systems

TeamTec has for many years been recording information from all lifecycle phases about their products on item-level in their ERP system. This data is the essential data basis for informed business decisions at the moment and provides a "passport" to every product. All data that is being acquired from other sources like both the AIS data as well as the on-board sensor data need to be mapped against this data basis. As this data mapping is highly specific to the respective external data sources, it is considered in both development tracks.

The ERP system holds much information about the products and the connected business processes. However, it is at the moment not envisioned to merge all the newly acquired data into the same repository, but to intelligently link the systems as to ensure smooth operation of both systems with minimal interference.

5. Results

The evaluation of both development tracks is an ongoing process. The evaluation iterations of the ship data integration prototype are developing potential for significant improvements in both efficiency and resource effectivity, meeting all specific objectives set. For the product data integration prototype, the implementation and thus also the testing is not as progressed and the evaluation of the system has not been completed.

Currently, it is estimated that for TeamTec the productive implementation of the ship data integration alone would save several hours of daily work time.

Together with the product data integration, the system will enable a better customer service due to easily enabling coordinated requests to the ship owning companies and a significant decrease in maintenance personnel travel as well as improving product performance.

6. Conclusion and Outlook

This paper gives an approach to the problem of Through-life Engineering Services (TES) like maintenance, repair and overhaul (MRO) management for marine auxiliaries producers. The producers have the problem, that they need to fit their MRO schedule into the often badly communicated schedules of the ships, on which their products are deployed. The approach presented utilizes the principles of the Internet of Things (IoT). It integrates data that is constantly being produced by the ships through the Automatic Identification System (AIS) as well as data that is being produced by the products themselves. The current state of the system evaluations already shows a significant potential for the use case owners which most likely also applies to many other companies in the sector. However, of course, there are some further adjustments to be made between the status presented in this paper to the productive implementation.

The identification of additional objectives has been introduced into the evaluation progress. It will be considered how the solution can be best applied to a group of companies in order to leverage the effects of joint TES. From the data analytics point of view, it will also be investigated how the MOL actions management can be further optimized by including historical data from the ships.

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